Assimilation of 3D Atmospheric Motion Vectors to Improve Subseasonal Numerical Weather Forecasts

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Why 3D winds?

Importance of global 3D winds in weather predictability

•Fill in data void regions, most notably over oceanic, tropical, and polar regions.

•This lack of data, especially wind information, is "the number-one unmet measurement objective for improving weather forecasts." (NRC 2007).

•Decadal Survey recommended a 3D tropospheric wind mission, using a space-based LIDAR instrument and/or the use of hyperspectral infrared measurements.

Why 3D winds?

•NASA’s 2015 workshop: Scientific Challenges and Opportunities in the NASA Weather Focus Area suggested other instruments to derive 3D winds, including the use of hyperspectral infrared measurements.

•NRC 2017:

- p. 3-76: "One of the most pressing science and application priorities in the coming decade is to better observe the properties in the PBL and lower troposphere and improve prediction of high-impact natural hazards such as severe air pollution outbreaks and tropical and winter storms, renewable wind energy applications, transport and distribution of global water and carbon in hydrological and energy cycles of the Earth system. Observing 3D winds is key to addressing these priorities to meet societal needs."

What are 3D winds from satellite sounders?

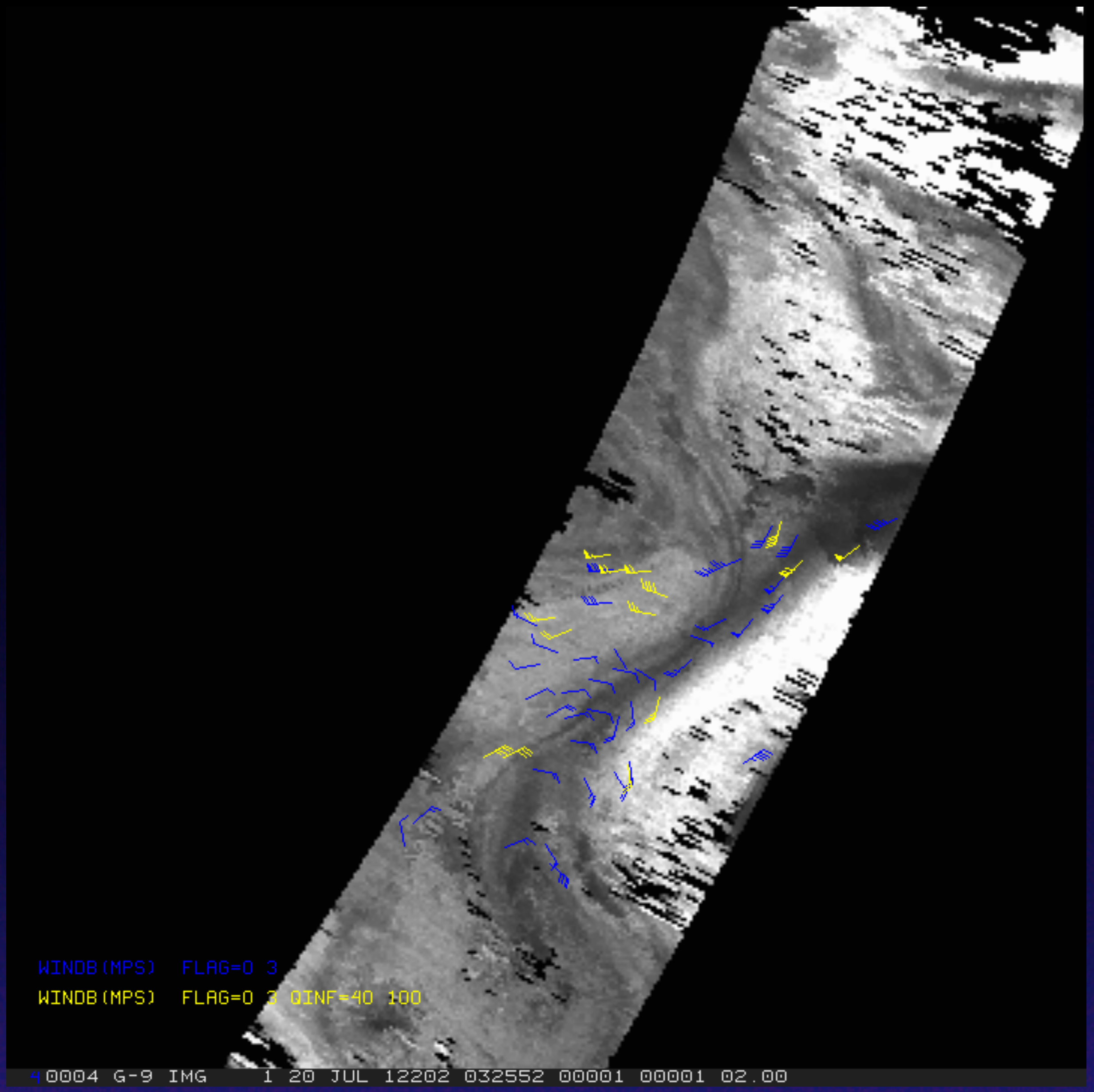
- Create images of horizontal fields of humidity and ozone, derived from retrievals using AIRS, CrIS, IASI

- Track humidity and ozone features over time

- Advantages:
  a) 3D wind distribution
  b) Implicit AMV height
  c) Clear sky and above cloud

- Current disadvantages:
  - Low spatial resolution (13.5 km)
  - Narrower swath compared to other LEO sensors (e.g., MODIS, VIIRS)

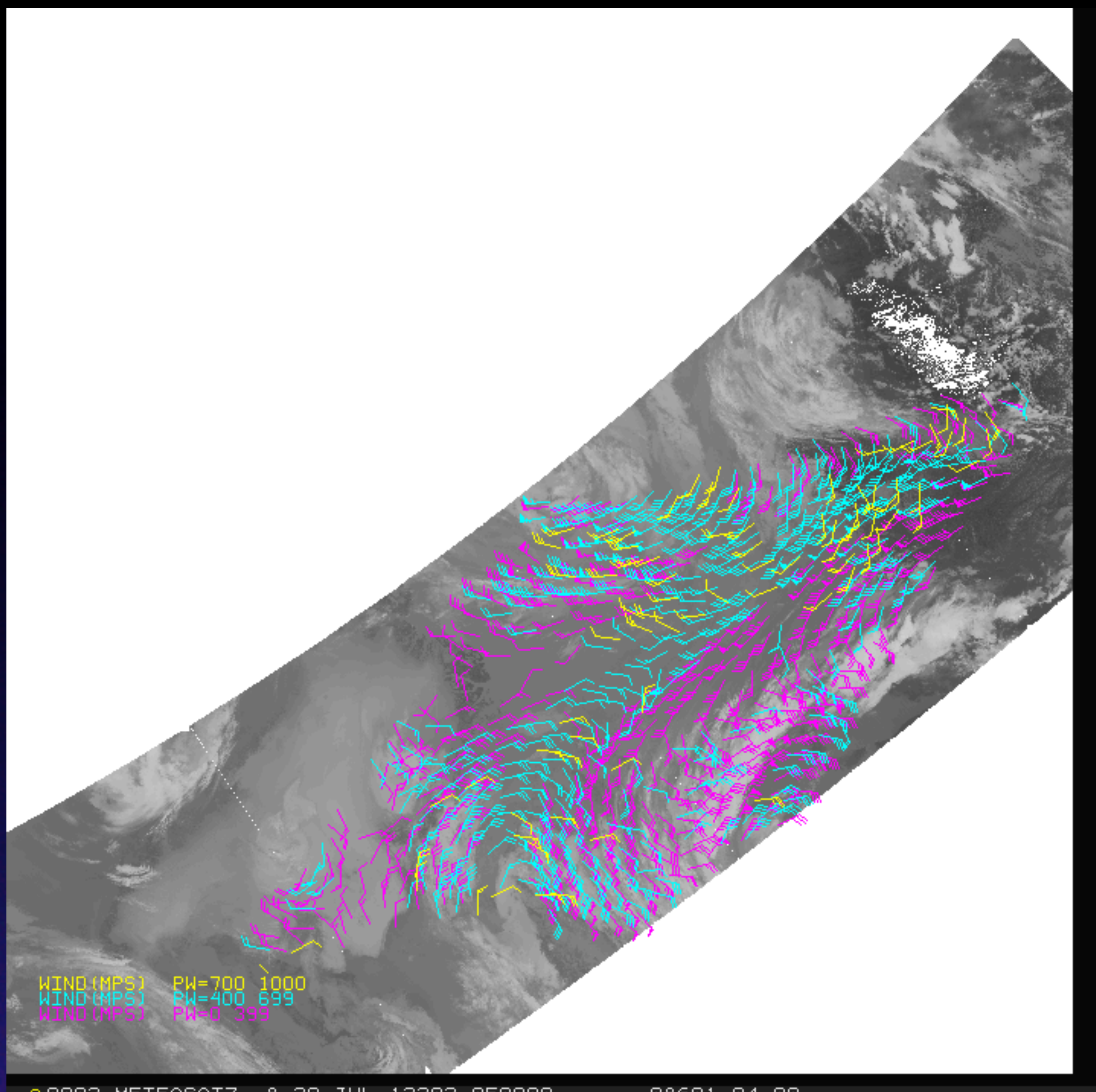
AIRS Humidity Retrieval Images at 400 hPa



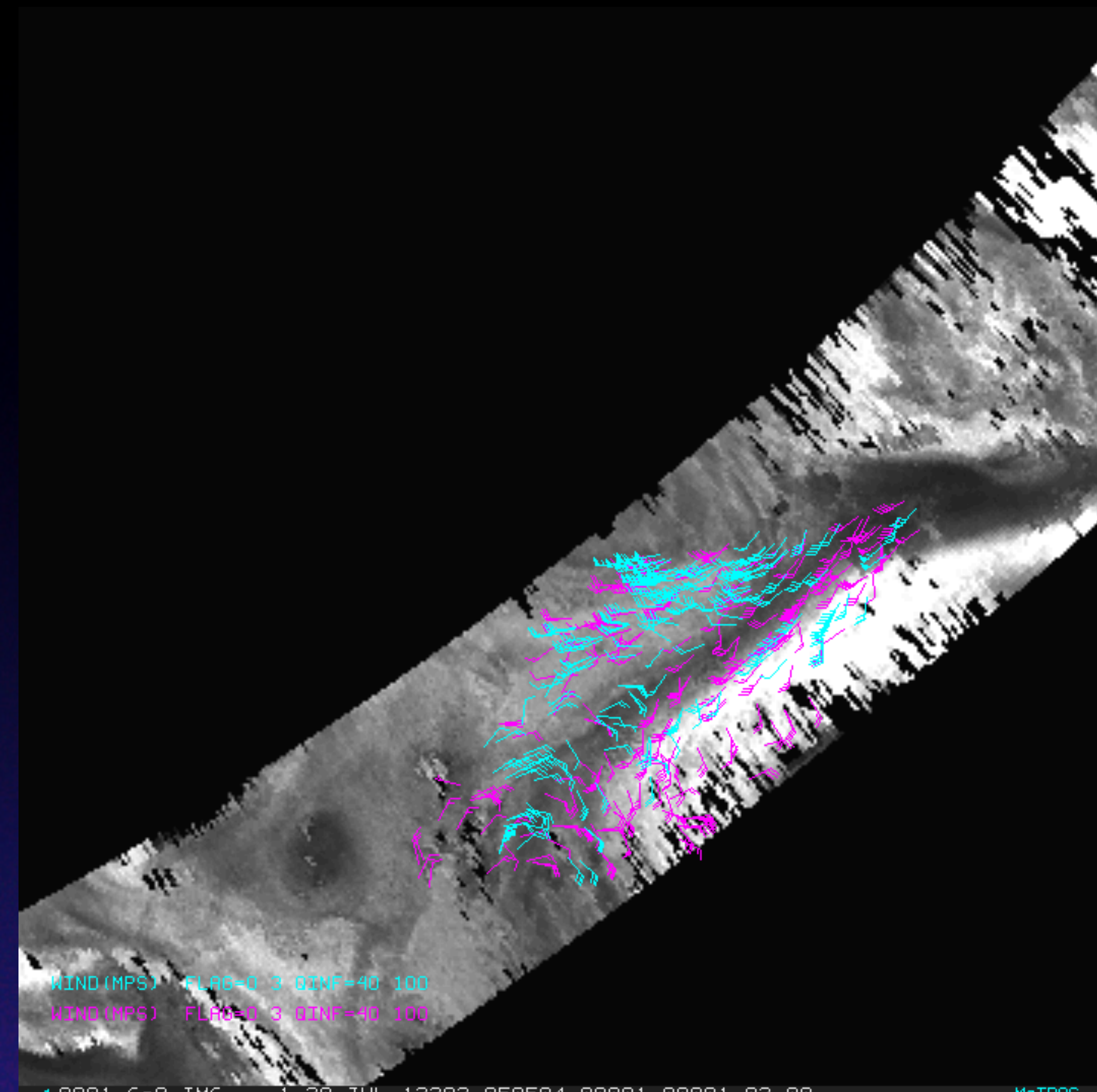
AIRS 20 July 2012 0325, 0505, 0643 UTC

Specific humidity retrievals
All winds (blue); Quality controlled winds(yellow)

Aqua MODIS AMVs
AIRS Retrieval AMVs at All Levels

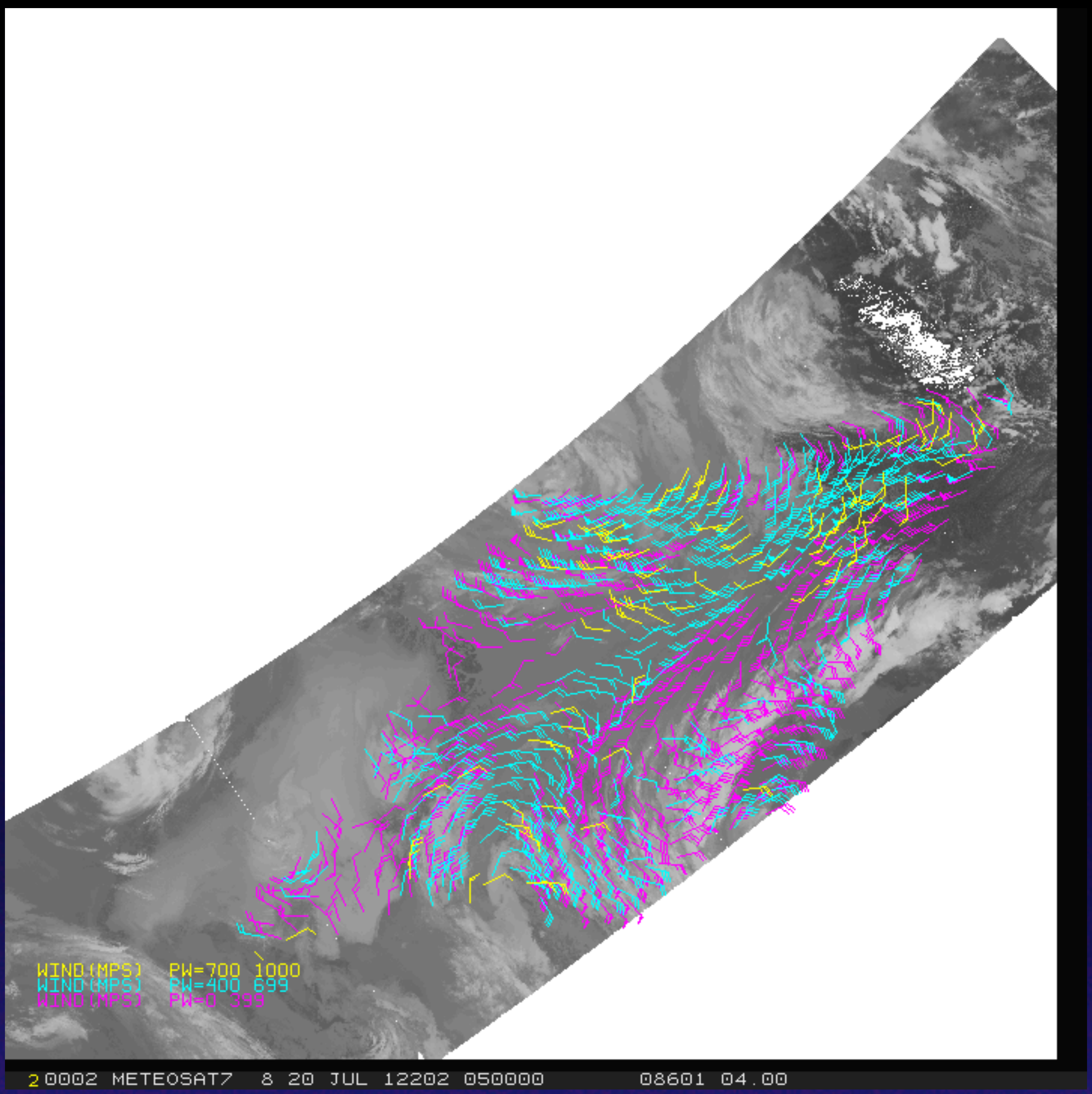


MODIS 20 July 2012 0551 UTC
Infrared and Water Vapor
(including clear sky)



AIRS 20 July 2012 0505 UTC
Ozone: 103 to 201 hPa Moisture:
359 to 616 hPa

Aqua MODIS AMVs
AIRS Retrieval AMVs at All Levels



MODIS 20 July 2012 0551 UTC
Infrared and Water Vapor
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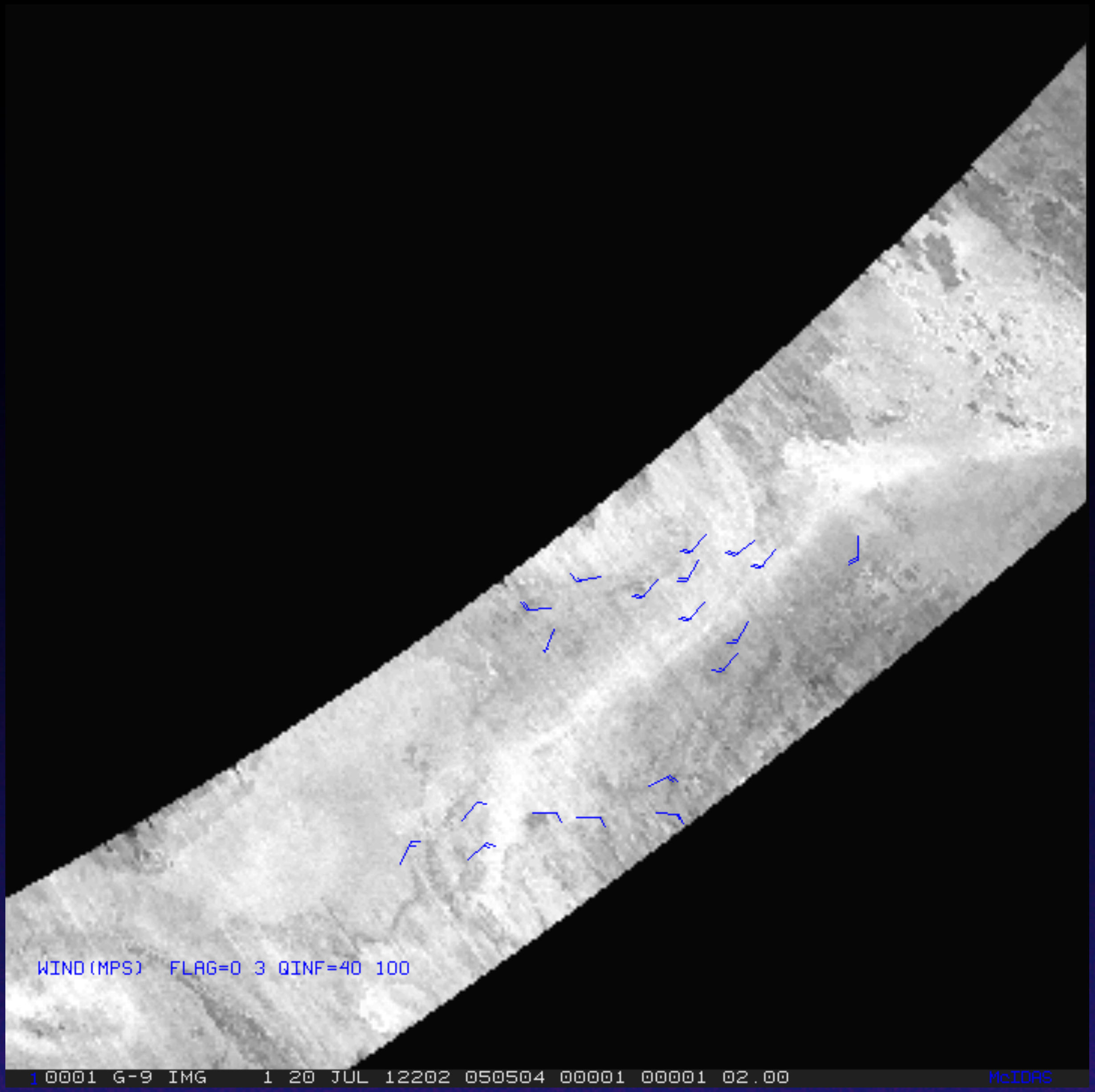
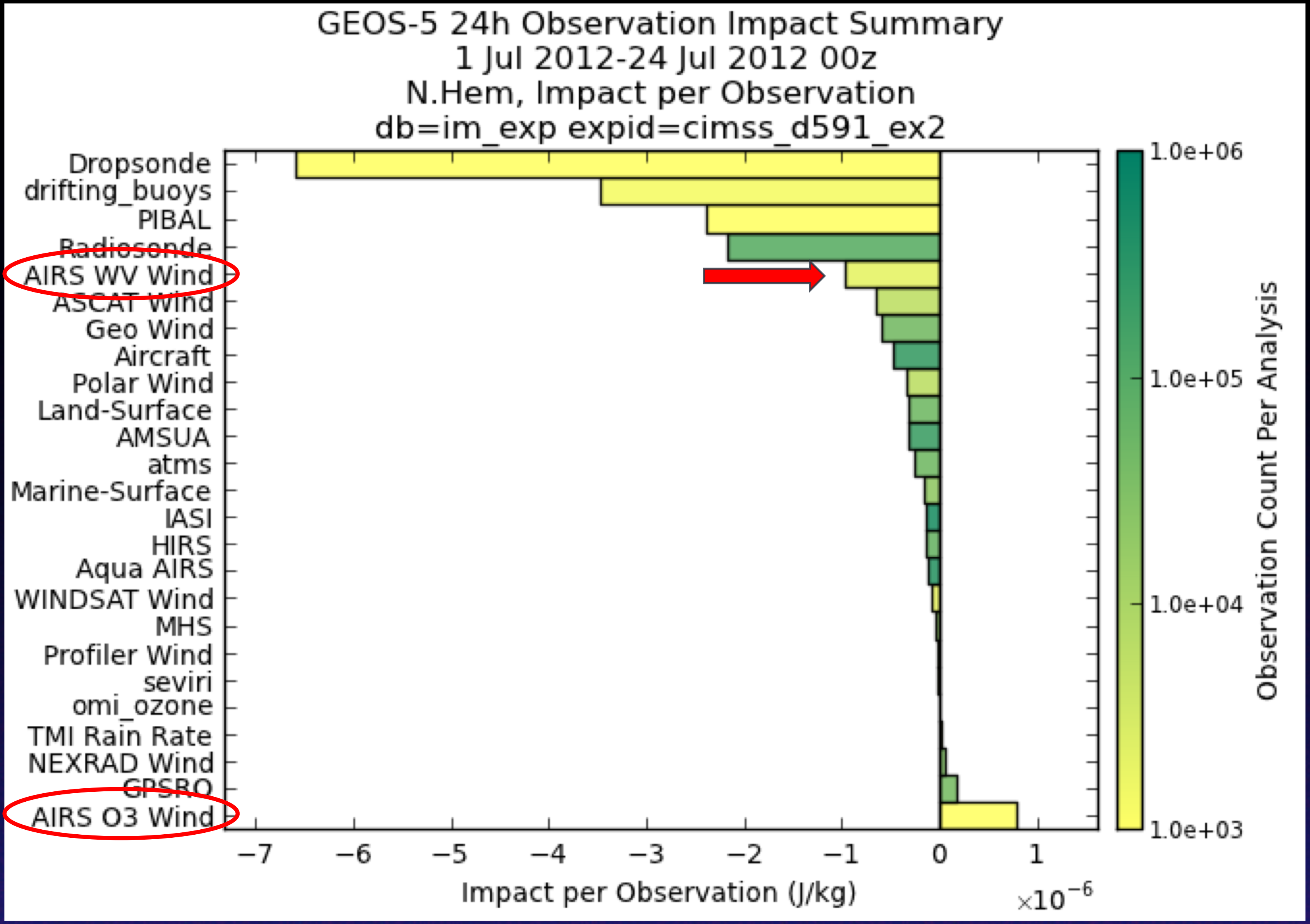


AIRS 20 July 2012 0505 UTC
Ozone: 103 to 201 hPa Moisture:
359 to 616 hPa

Impact per observation

2012 Experiment



1 – 24 July 2012 00 UTC

GEOS-5 Forecast Impact: ACC
Two experiments in July 2012

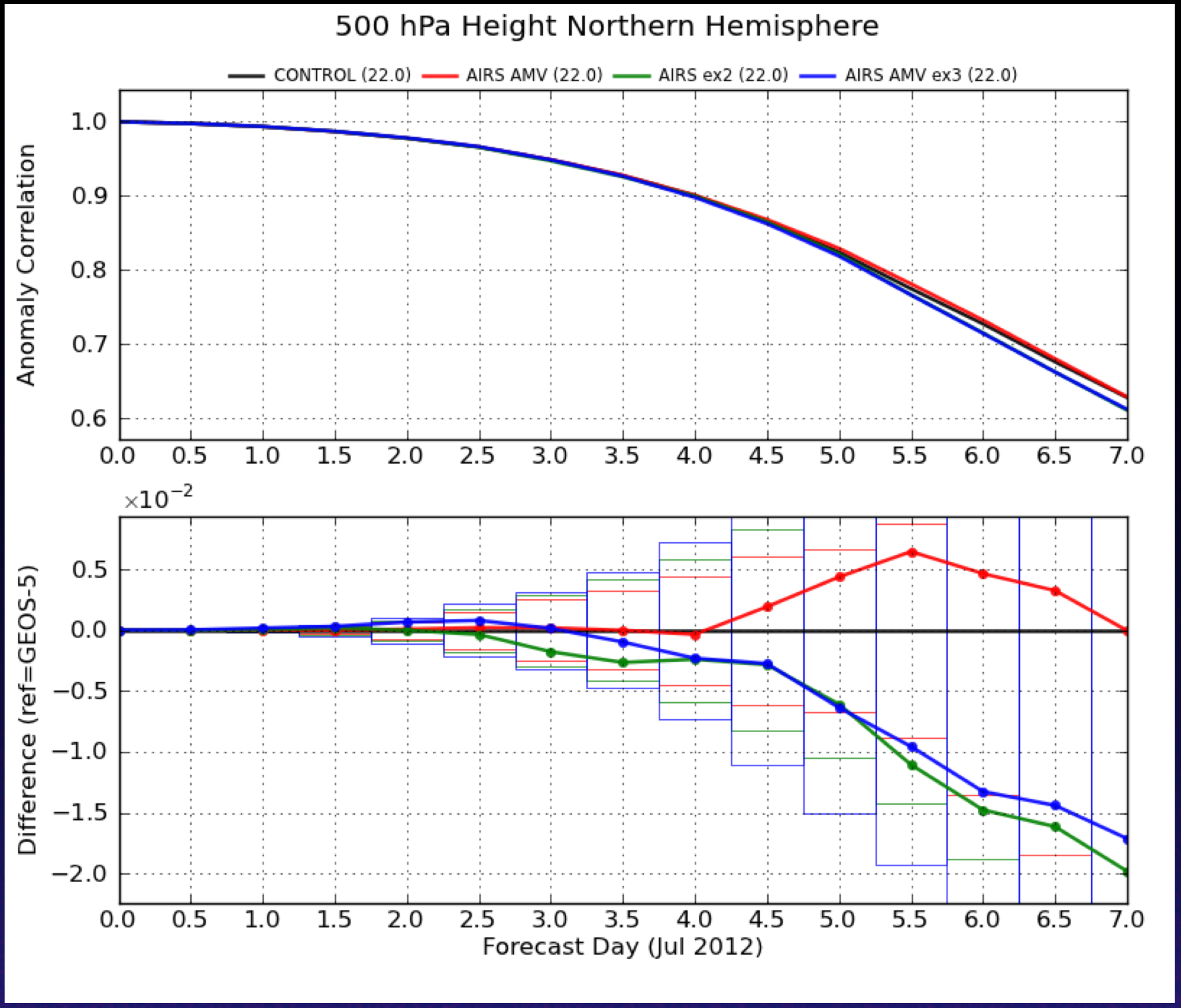
Control in black.

Red: Addition of AIRS AMVs. Slight improvement after Day 4 (not statistically significant).

Blue: Removal of the MODIS AMVs decreases ACC score:
•AIRS AMVs can not offset loss of MODIS AMVs

AIRS AMVs complement the MODIS AMVs

AIRS AMVs are in clear sky or above cloud regions; MODIS AMVs include cloud-tracked features.



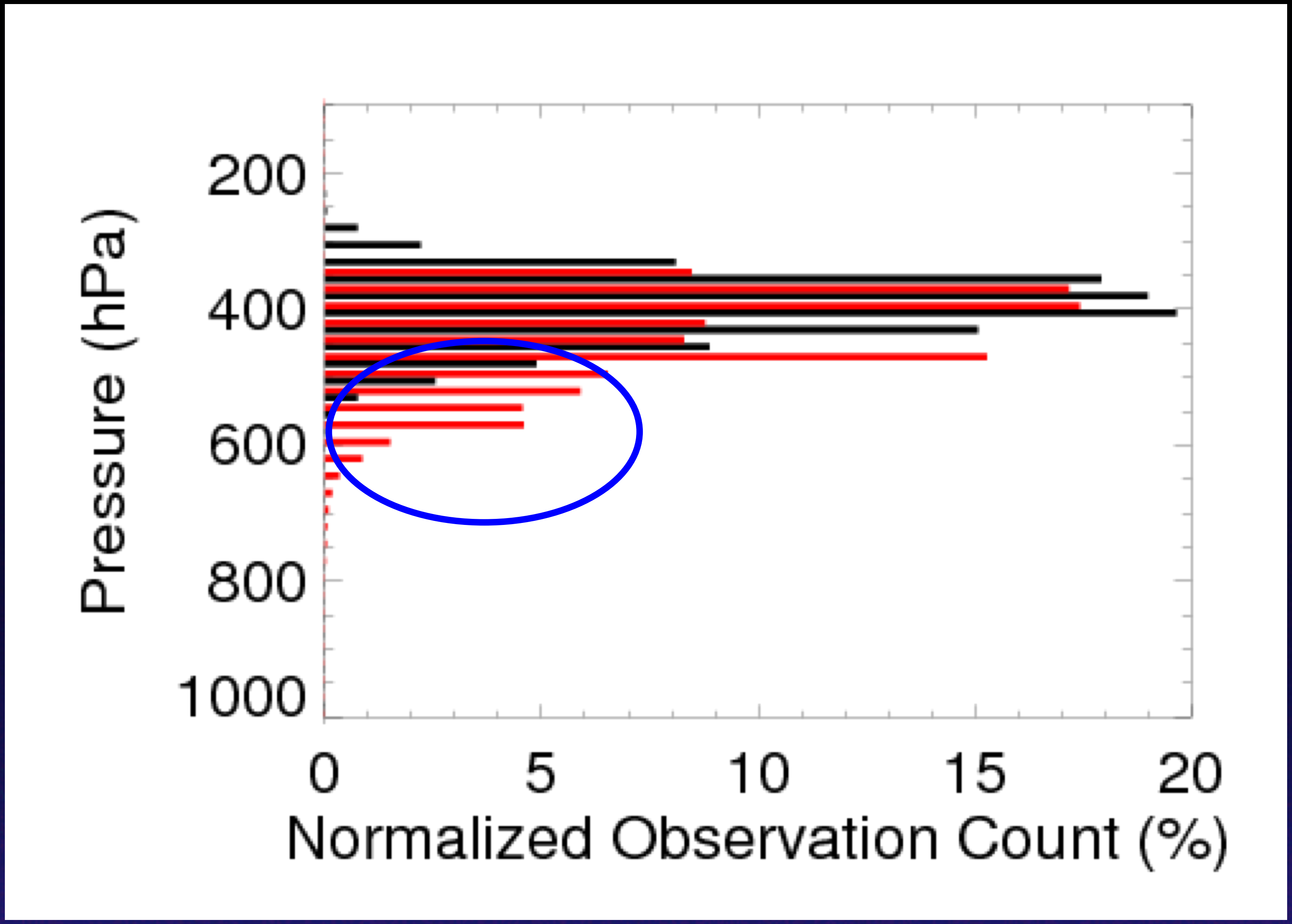
500 hPa Northern Hemisphere
1 – 24 July 2012 00 UTC

AIRS winds preliminary evaluation

NASA/GMAO in 2015

AIRS winds extend lower in atmosphere than MODIS winds

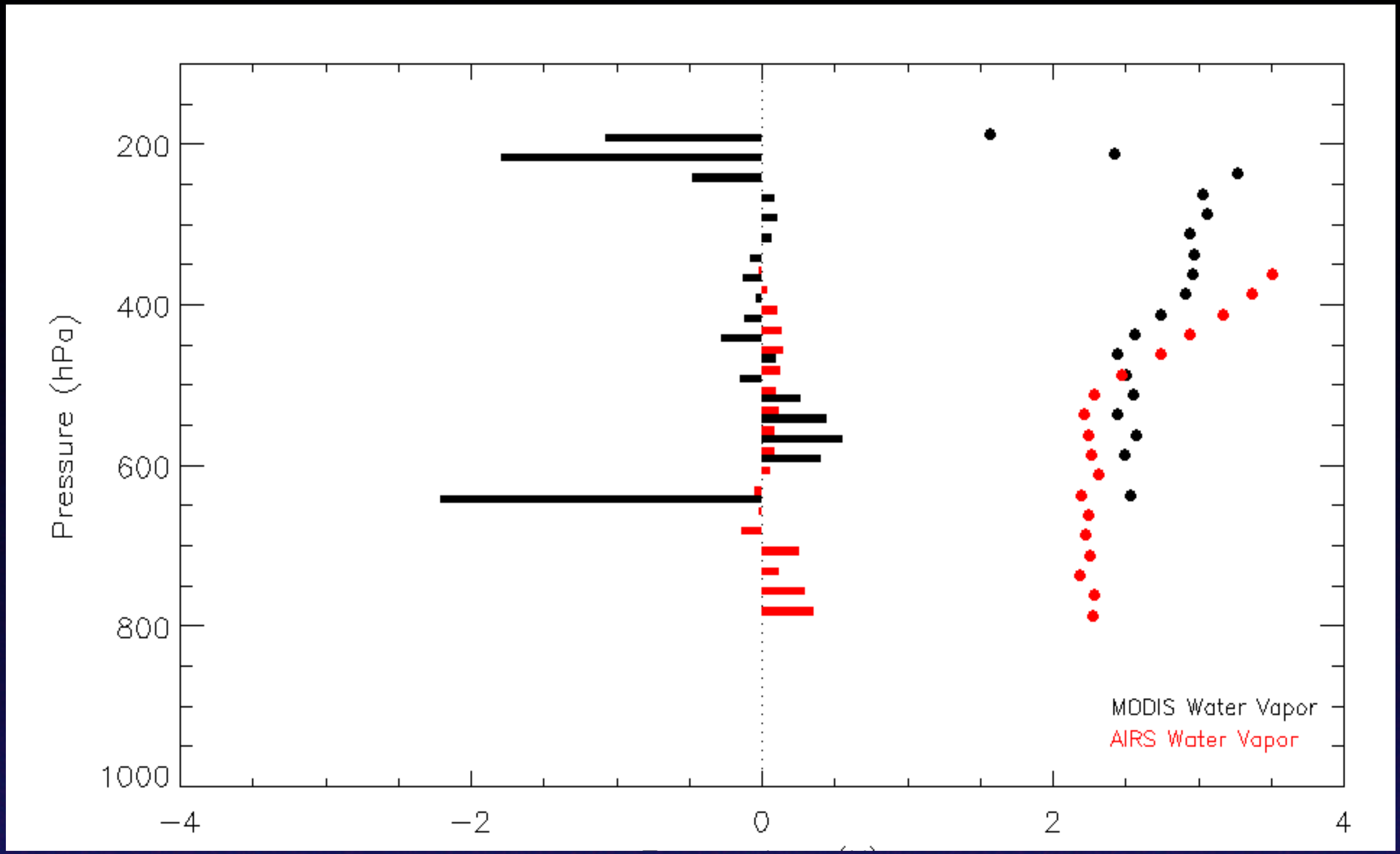
Extending even lower in atmosphere is expected using higher resolution instruments (better cloud clearing)



Observation Counts: Histogram of averaged normalized counts for 6-hour cycles for AIRS (red) and MODIS (black) water vapor winds.
May to July 2015

AIRS winds preliminary evaluation
NASA/GMAO in 2015

AIRS retrieval winds show similar bias and standard deviation as MODIS polar winds, when compared to the model background.



Observation Departures: Mean and standard deviation (ms^{-1}) for AIRS (red) and MODIS (black) water vapor winds May to July 2015

Wind uncertainty

JPL: Derek Posselt and Longtao Wu

How well does tracking clouds and water vapor features represent atmospheric motion?

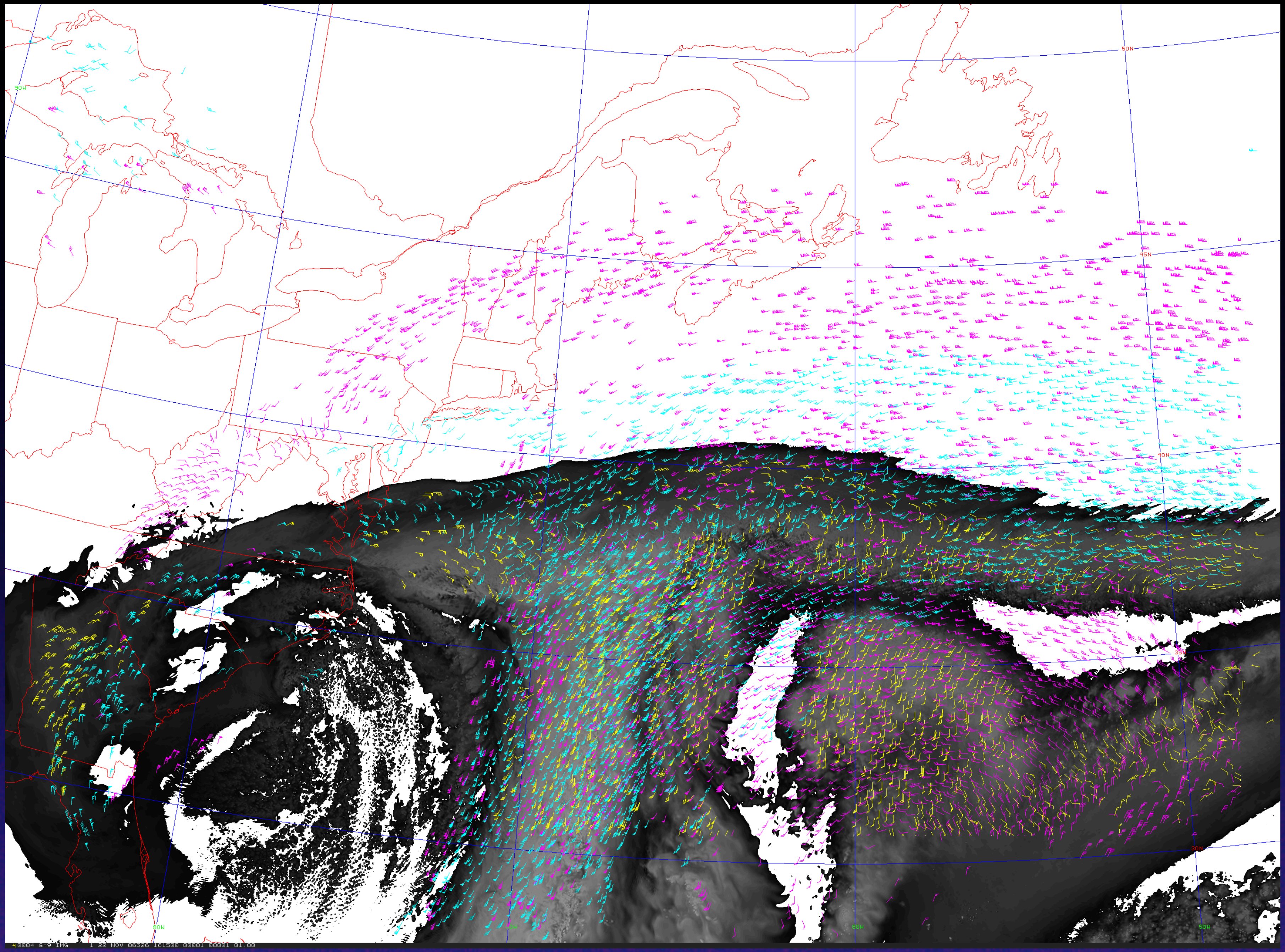
Early work by Hasler (1976): Motion of high-level clouds differs from actual wind by 3-5 m/s

Comparison of AMVs to RAOBs: RMS vector difference 6-7 m/s

Use high-resolution nature run (1.3 km WRF) to track humidity and cloud features. Compare to model wind field.

Wind uncertainty
JPL: Derek Posselt and Longtao Wu

High: magenta
Middle: cyan
Low: yellow



RMS vector difference: 4 m/s for 27,000 co-located AMVs

New Project

- NASA ROSES 2017 A.37: The Science of Terra, Aqua, and Suomi NPP
- Proposal selected: Assimilation of 3D Atmospheric Motion Vectors to Improve Subseasonal Numerical Weather Forecasts
    - PI: D. Santek Co-I: D. Posselt (JPL), W. McCarty (NASA/GMAO)
    - 3 years
    - Previous work only used AIRS; this extends to CrIS and IASI and improvements to algorithm (SSEC)
    - Better quantify winds uncertainty (JPL)
    - Evaluate impact in longer range forecasts, on the order of 2 weeks (GMAO)

Overall Goals

- Improve the 3D winds product (SSEC):
  - Use all hyperspectral instruments (AIRS, CrIS, IASI) on the operational polar orbiting platforms to derive AMVs, which will substantially increase the number of winds and the spatial coverage,
  - Single satellite and mixed-satellite winds
  - Updating the winds algorithm from a cross-correlation to an optical flow technique, as the cross-correlation does not perform well with sharp gradients,
  - Re-evaluate AMVs from tracking ozone features in stratosphere

Overall Goals

- Quantify the AMV uncertainty to better characterize the errors (vector and height assignment) for use in assimilating the winds. (JPL)
- Assimilate into GEOS-5 either for specific cases or in a routine mode over a long period of time, and evaluate impact on extended-range forecasts (~ 10-14 days) (GMAO)
- Increase understanding of stratosphere/troposphere interactions (e.g., TPV effect on polar jet position and cyclogenesis) and impact on extended-range forecasts and high-impact weather events (SUNY Albany)

Year One Goals

- Expand the AIRS-only AMV algorithm to CrIS and IASI clear-sky retrievals.
- Evaluate retrieval products and assess quality/uncertainty
- Transition winds algorithm from using cross-correlation to optical flow
- Perform control and control+AIRS AMV assimilation and modeling experiments in the GEOS
- Extend assimilation system in preparation for CrIS, IASI, and mixed-satellite winds

Status

- SSEC:
  - AIRS 3D winds product available in real-time
  - Investigating optical flow method
- JPL
  - Continuing wind uncertainty experiments with high resolution nature run (1.3 km resolution)
- GMAO
  - Running case studies with current 3D winds product
- SUNY Albany
  - Identifying graduate student

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